UTILIZATION OF COAL BOTTOM ASH AND FINE COCONUT SHELL AS PARTIAL SAND REPLACEMENT IN CONCRETE

PUTERI NATASYA BINTI MAZENAN

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To my beloved mother and father,

My beloved family, husband,

And my son, Mohamad Adam Rayyan

Thank you for always supporting and encouraging me,

And always pray for my success.

Alhamdulillah.

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ABSTRACT

Sustainable development and environmental protection have become the key goals of the modern society. Nowadays, huge volumes of coal bottom ash (CBA) are disposed of in coal ash ponds or landfills. On the other hand, the coconut industry is facing disposal problems due to the slow decomposition process of coconut shells which has led to the accumulation of coconut shell piles. Therefore, this study aims to determine the properties of sustainable concrete containing CBA and fine coconut shell (FCS) as partial sand replacement. Normal concrete design with compressive strength of 30 MPa strength at 28 days curing age and a water-cement ratio of 0.50 was used in this study. The percentages of CBA used were 5%, 10%, 15% and 20% while the percentages of FCS used were 2%, 4%, 6% and 8% where its replaced by volume. The slump test was performed to determine the workability of the fresh concrete. The specimens were cured in a water tank for 7, 28, 56 and 90 days before they were tested in terms of compressive strength, splitting tensile strength and water absorption. Design Expert software was used for Response Surface Method (RSM) analysis to determine the optimum percentages of CBA and FCS as partial sand replacement in concrete. CBA and FCS were inserted as factors (input) whereas the results of fresh and hardened concrete from the experimental work were inserted as response (output) in the software in order to determine the optimum percentage. As conclusion, the workability of the concrete decreased with the incorporation of CBA and FCS in concrete while the compressive strength and splitting tensile strength were improved. In addition, the percentage of water absorption increased as both CBA and FCS are capable of absorbing water. It was found that the optimum percentages of CBA and FCS were 10% and 6% respectively. These percentages resulted in the optimum performance of concrete in terms of workability and strength in this study.

ABSTRAK

Pembangunan yang lestari serta perlindungan terhadap alam sekitar telah menjadi matlamat utama dalam masyarakat moden. Kini, abu arang batu (CBA) telah dibuang ke dalam kolam abu arang batu ataupun tapak pelupusan sampah. Selain itu, industri kelapa sedang menghadapi masalah pelupusan disebabkan proses penguraiannya yang sangat lambat sekaligus menyebabkan longgokan tempurung kelapa yang banyak. Oleh itu, tujuan kajian ini adalah untuk menentukan sifat konkrit lestari yang mengandungi CBA dan tempurung kelapa halus (FCS) sebagai bahan pengganti separa pasir. Konkrit normal dengan kekuatan 30 MPa pada usia matang 28 hari dengan 0.50 nisbah air-simen digunakan dalam kajian ini. Kadar peratus CBA yang digunakan ialah 5%, 10%, 15% dan 20% manakala kadar peratus bagi FCS ialah 2%, 4%, 6% dan 8% di mana ianya menggantikan pasir berdasarkan isipadu. Ujian kericihan telah dijalankan untuk menguji kebolehkerjaan konkrit basah. Spesimen diawet di dalam air selama 7, 28, 56 dan 90 hari sebelum diuji dengan ujian kekuatan mampatan, ujian kekuatan tegangan serta ujian penyerapan air. Perisian *Design Expert* digunakan untuk analisis *Response Surface Method* (RSM) bagi menentukan peratusan optimum bagi CBA dan FCS sebagai bahan pengganti separa pasir didalam konkrit. CBA dan FCS dikumpulkan sebagai faktor (*input*) manakala data dari eksperimen yang telah dijalankan dikumpulkan sebagai tindak balas (*output*) dalam perisian bagi menentukan peratusan yang optimum. Kesimpulannya, kebolehkerjaan konkrit menurun dengan penggunaan CBA dan FCS didalam konkrit manakala kekuatan mampatan dan tegangan menunjukkan peningkatan. Tambahan itu, peratusan penyerapan air meningkat disebabkan oleh CBA dan FCS merupakan bahan yang menyerap air. Peratusan optimum yang ditemui bagi CBA dan FCS masing-masing adalah 10% dan 6%. Peratusan ini menghasilkan prestasi konkrit yang optimum bagi kebolehkerjaan dan kekuatan .

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	-	Analysis of variance
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CBA	-	Coal bottom ash
CI	-	Confidence interval
CV	-	Coefficient of variation
df	-	Degrees of freedom
DOE	-	British Department of Environmental
FCS	-	Fine coconut shell
fc	-	Compressive strength of concrete
ft	-	Tensile strength of concrete
OPC	-	Ordinary Portland Cement
RSM	-	Response Surface Method
SEM	-	Scanning Electron Micrograph
VIF	-	Variance inflation factor

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Concrete is the most used construction material for decades worldwide. Daily global concrete production has reached a value of more than one tonne. The production of 1 m^3 of concrete requires almost 1 m^3 of natural aggregate and this leads to the depletion of natural aggregate. The use of aggregates in construction is one of the most significant parts which contribute to concrete strength (Ganiron Jr, Ucol-ganiron, & Ganiron III, 2017; Radonjanin, Malešev, Marinkovic, & Malty, 2013).

Since concrete production causes the depletion of natural aggregates, many research studies (Dahiya & Dharni, 2015; Kanojia & Jain, 2017; Kim & Lee, 2011; Radonjanin *et al*., 2013; Sata, Jaturapitakkul, & Kiattikomol, 2004; Singh & Siddique, 2013) have been done on natural aggregate replacement material such as oil palm shell, recycled concrete aggregate, bottom ash, plastic, coconut shell, blast furnace slag, and so on. Environmental protection and sustainable development are the key goals of the modern society by the end of the 20th century. The usage of waste materials as construction material helps reduce dumping spaces, conserve natural resources and maintain a clean environment. The environmental impact can be lowered by reducing, reusing or recycling waste which are preferable to waste disposal as shown in Figure 1.1.

There are many possibilities to use industrial and agricultural waste as sand substitution materials in the production of concrete since many researchers have conducted studies on these types of wastes. Until this point, no published data on the combination of coal bottom ash (CBA) and fine coconut shell (FCS) as partial sand replacement in concrete is available.

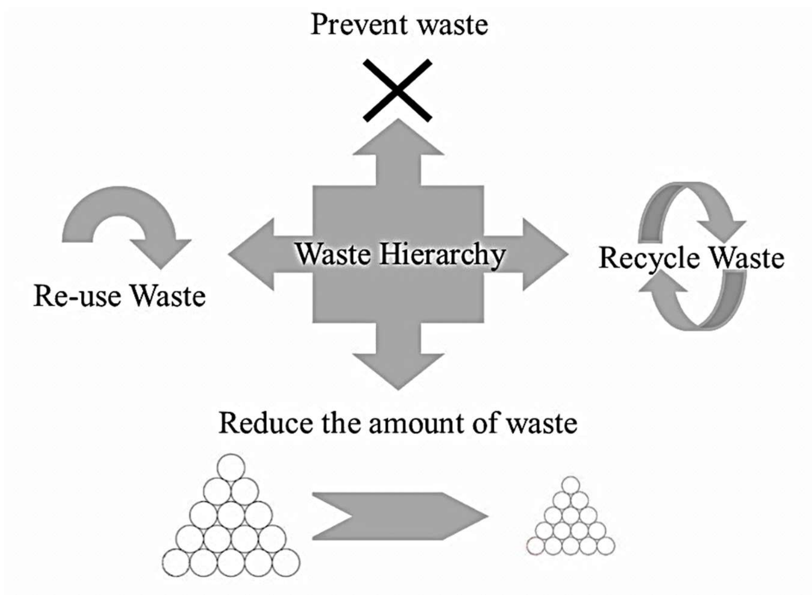

Figure 1.1: Waste Hierarchy (Kambli & Mathapati, 2014)

Basically, CBA is a by-product of municipal solid waste incinerators and coal fueled power stations where it consists of irregular particles measuring 10 mm to 15 mm in size. Moreover, CBA is an inert material and it can be used as an aggregate for producing construction materials (Safiudin, Jumaat, Salam, Islam, & Hashim, 2010). Since CBA particles can vary in size from fine gravel to fine sand with very low percentages of silt-clay sized particles, it can be used as aggregates (Ghafoori & Buchole, 1997). CBA and river sand have similar properties and particle size distribution. This makes CBA suitable to be used as fine aggregate in concrete production (Raju, Paul, & Aboobacker, 2014). Since CBA has similar particle size distribution as fine aggregate, it can therefore be used as partial sand replacement material.

On the other hand, coconut has long been a source of income for many individuals as there are various uses of coconuts (Ganiron Jr *et al*., 2017). After coconut flesh is scraped out, the coconut shell is normally discarded as waste (Gunasekaran, Annadurai, & Kumar, 2013). Coconut shells can decrease the cost or improve the mechanical properties of composite material as it can substitute current materials used in commercial products (Ganiron, 2013). In addition, coconut shells have high strength and modulus properties along with the added advantage of high lignin content. Besides, it also absorbs less moisture due to its cellulose content (Chanap, 2012). Therefore, this study aims to incorporate CBA and FCS as partial sand replacement materials in concrete. The combination of these two materials will promote a way to produce sustainable materials and buildings in civil engineering construction industry.

1.2 Problem statement

In the construction industry, concrete is the main construction material whereas cement, coarse aggregate and river sand are its constituent materials. A high demand for natural resources such as sand has increased problems in the production of concrete. This will subsequently increase the production cost of construction materials and the demand for affordable houses due to the difficulty faced by manufacturers to locate an adequate supply of natural materials. The cost of concrete production primarily depends on the cost of its constituent raw materials. The cost of construction materials is increasing day by day due to high demand, scarcity of raw materials and high energy costs (Imbabi, Carrigan, & Mckenna, 2013).

The consumption of natural sand in concrete production is very high and this causes a shortage of natural fine aggregate which is suitable for construction in many countries (Rashad, 2016). It is reported that 1 m^3 of concrete contains almost 1 m^3 of aggregates (Radonjanin *et al.*, 2013). Natural sand is the most common material used in the construction industry as natural fine aggregate. This has caused the availability of good quality natural sand to continue decreasing in the last 15 years (Rashad, 2013). Thus, waste or agricultural by-products should be used to partially or fully replace fine aggregate in construction activities. Hence, this will help reduce the demand for natural raw materials and save landfill space (Rashad, 2016). Moreover, the reuse and recycling of suitable materials for the effective replacement of cement and fine aggregate in the construction sector are due to a lack of natural resources worldwide (Kumar, Mahendran, Nathan, Sathya, & Thamaraikannan, 2017).

One possibility is to recycle and reuse industrial and agricultural wastes as fine aggregate. Therefore, CBA and coconut shell were selected as combination waste materials. CBA is usually disposed in coal ash ponds or landfills along with unutilised fly ash. A large amount of CBA is produced due to the high consumption of coal. Hence, these will increase disposal expenses due to the need for large areas for waste disposal (Muhardi *et al*., 2010). The increasing amount of CBA disposed causes a threat to the environment and poses risk to human health. Hazardous constituent materials in CBA can pollute groundwater or surface water which can affect the ecosystem and living organisms (Singh & Siddique, 2013).

Coconut shell is a type of solid waste generated by agricultural activities. More than 60% of domestic waste volumes are represented by coconut shell. This presents serious disposal problems for the local environment (Gunasekaran, Annadurai, & Kumar, 2012). Coconut farmers traditionally dispose husks, spate, petiole and leaves by burning or allowing farm wastes to rot in the field. Moreover, burning agricultural waste leads to air pollution, soil erosion and decreased biological activity in soil that will eventually decrease soil fertility (Ganiron Jr *et al*., 2017). On the other hand, allowing the waste to rot in the field may improve the productivity of soil. However, the process of decomposition is very slow, causing the accumulation of agricultural waste that can lead to sanitary problems in coconut plantations since decaying debris is the ideal breeding place for coconut pests (Brigado & Salvacion, 2004).

Both CBA and coconut shell have the potential to be used as replacement materials in the construction industry. Besides being beneficial to the environment, construction costs will be reduced with the use of industrial and agricultural waste in the construction industry. Most researchers (Ibrahim, Hamzah, Jamaluddin, Ramadhansyah, & Fadzil, 2015; Kambli & Mathapati, 2014; Kanojia & Jain, 2017; Raju *et al*., 2014; Rao, Swaroop, Rao, & Bharath, 2015; Singh & Siddique, 2016) studied the effect of using CBA as partial sand replacement and coconut shell as coarse aggregate replacement in concrete. They found one of the advantages of using CBA able to develop the strength of concrete other than lightweight concrete is produced. Also, the physical properties of CBA are light material and more brittle as compared to the natural sand. It has irregular shape of particles and porous surface texture other than have rough surface texture. Study conducted by Ibrahim *et al*. (2015) and Raju *et al*. (2014) found the workability of concrete decreased with the utilization of CBA as partial sand replacement. However, both of the researchers (Ibrahim *et al*., 2015; Raju *et al*., 2014) highlighted on the improvement in the concrete strength as CBA used as partial sand replacement in concrete. On the other hand, Rao *et al*., (2015) and Kanojia

& Jain, (2017) conducted the study of the coconut shell where they found both workability and strength of concrete decreased with the replacement of coarse aggregate with coconut shell in concrete. Currently, there is a lack of data on the use of CBA and FCS as partial sand replacement material in concrete. It is hoped that this study will result in the significant improvement of engineering properties and durability of concrete.

1.3 Objectives of study

The aim of this study is to determine the properties of sustainable concrete containing CBA and FCS as partial sand replacement. This aim can be achieved through the objectives below:

i. to determine the physical properties of CBA and FCS,
ii. to investigate the workability, strength, and durability of concrete containing CBA and FCS as partial sand replacement materials, and
iii. to analyze the optimum percentage of CBA and FCS as partial sand replacement materials in concrete by using Research Surface Method (RSM) in Design Expert software.

1.4 Scopes of study

This study focuses on the properties of sustainable concrete containing CBA and FCS as partial sand replacement. In this study, the normal concrete design was designed with the compressive strength of 30 MPa at 28 days and the water-cement ratio of 0.50. Sieve analysis, fineness modulus and specific gravity tests were conducted on sand, CBA and FCS to determine their physical properties. The percentages of CBA used were 5%, 10%, 15% and 20% while the percentages of FCS used were 2%, 4%, 6% and 8%. The replacement percentages of CBA and FCS were calculated by volume replacement due to the huge difference between the specific gravity of CBA and FCS and the specific gravity of sand.

Four tests were carried out namely workability tests, compressive strength tests, splitting tensile tests and water absorption tests. Compressive strength and water absorption tests were conducted on 100 mm x 100 mm x 100 mm cubes while the splitting tensile test was conducted on samples measuring 100 mm in diameter and 200 mm in height. All the samples were cured for 7, 28, 56 and 90 days. The results obtained at each age were reported as the average of three sample tests. Then, all the data from the experimental work was inserted and analysed in the Design Expert software by using RSM analysis in order to determine the optimal percentages of CBA and FCS in concrete.

1.5 Significance of study

This study investigates the effects of CBA and FCS as partial sand replacement on the engineering properties of concrete which include workability, compressive strength, tensile strength and percentage of water absorption. The use of CBA and FCS in concrete enhances the strength and properties of concrete due to the influence of the physical properties of CBA and FCS. This helps to develop sustainable concrete which is better than normal concrete in terms of workability, strength and water absorption. On the other hand, this study also benefits the construction industry by helping to minimise the usage of natural aggregates in concrete production. Besides, it also helps to reduce the use of landfills and negative environmental impact. This study offers an alternative to raw materials through the utilisation of waste in concrete production.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review obtained from previous study related to the current study which started with the introduction of concrete followed by the literatures on the substitution materials in concrete (CBA and FCS) are explained and gathered in the subtopic below. Moreover, the past works on the RSM and its application in process of optimization and modelling also explained.

2.2 Concrete

Concrete is a strong, durable, low environmental impact, building material and which has been used for over 2,000 years and it is known as the most widely used construction materials in the world. Also, concrete is the best known for its dependable nature and long lasting material (Naik & Moriconi, 2005). Malhotra (2004) stated that a engineer that used more concrete in the construction is a good engineer. Concrete can provide flexibility in design other than inexpensive, and are environmentally more responsible than steel or aluminum structures (Cement Association of Canada, 2004). The great advantage of concrete is that it can choose its mixing materials and then users able to improve and optimize the unique properties of each components to develop a high quality, strong construction material of high impermeability (Swamy, 2007).

Annually, more than 10 billion tons of concrete produced until it is considered as the most important building material (Meyer, 2009). By the year 2050, it was

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